SECTION 2

MIXING ZONE DELINEATION

As early as 1990, in preparation for filing their NPDES permit renewal, Amoco embarked on a series of studies to delineate the mixing of Outfall 001 effluent with Lake Michigan waters in the area of the discharge. The studies were based on standard USEPA methods and guidance to assess the mixing processes. In 1989 when the Indiana Water Quality Standards were passed, the Hearing Officer Recommendations to the Indiana Water Pollution Control Board (WPCB) were: "in the next review/revision of the rule, changes be considered which would allow for the determination of a mixing zone for discharges into Lake Michigan on a case-by-case basis for substances listed in 327 IAC 2-1-6(j)". Amoco's studies were conducted to gather information to respond to the WPCB's concern with the use of mixing zones in lakes, and ascertain whether the mixing of effluent with the Lake is rapid and immediate.

INITIAL MIXING ZONE ANALYSIS

A mixing zone dispersion analysis and an effluent treatability assessment were conducted during the Spring of 1990. At that time, only dispersion computer modeling was performed as part of the mixing zone investigation. The report "Mixing Zone Dispersion Modeling Analyses and Effluent Treatability Assessment" summarized the findings of the computer modeling for Outfall 001. Amoco reviewed the results of this report and their approach to water quality management with the Indiana Department of Environmental Management (IDEM) on October 11, 1990.

The predictive side-channel surface discharge model, known as Prych-Davis-Shirazi (PDS) Model, originally developed at the Massachusetts Institute of Technology, has been accepted by the USEPA (1985 TSD) for use as a mixing zone model. The PDS model was used to simulate the discharge of 001 without accounting for the interaction with Outfall 002. Thus, a conservative relative estimate of jet induced mixing was provided. The PDS model allows the qualitative description of plume dimensions and dispersion for various wind and other environmental and operational conditions. Graphic representations of the PDS model results for the prevailing southerly winds are presented in Figure 2-1. These plan views show outer plume boundaries and plume centerline to the point where 10:1 dispersion is achieved.

The results from the mixing zone dispersion modeling study were believed to provide a fair, conservative representation of actual conditions. However, because of the complexity of the plume interactions between Outfalls 001 and 002, ADVENT recommended that a field dye-dispersion study be conducted to investigate the actual mixing process of the Amoco discharges and to assess the ability to predict attainment of receiving water quality standards.

MIXING ZONE FIELD STUDY

In order to quantitatively determine the actual mixing of Outfall 001 effluent with the Lake Michigan water, a mixing zone delineation study was performed. The amount of mixing occurring between an effluent and receiving water was measured using a non-degradable dye added to the effluent. On-water sampling locations were controlled by anchors with position confirmation from surveying equipment. The amount of mixing was defined by location and in-situ measured ratio of non-degradable substances.

Methodology

The field study was conducted from August 12 to 16, 1991 (with supplemental measurements collected October 22 and 23) to analyze mixing characteristics of the Amoco discharges. The findings of the study were presented to IDEM April 6, 1992.

The study focused on the collection of dye dispersion data and water quality parameters to examine the mixing zone characteristics of Lake Michigan near the Amoco discharges. The field study was also designed to collect data for determination of the influences of wind speed and direction (major influences on Lake currents) on plume projections, as well as the effects of temperature gradients on the mixing mechanisms between the discharges and the Lake.

The mixing zone study consisted of directly measuring the dispersion of effluent from Outfall 001 into the Lake by injecting a nontoxic water-tracing dye continuously into the discharge. The resultant dye concentrations were then measured to define the dispersion occurring between the Lake Michigan receiving waters and the Outfall 001 effluent. Two specific hydraulic zones were defined from the study and these included the jet entrainment zone, or Zone of Initial Dilution (ZID), and the far-field or total mixing zone (TMZ). The Jet Entrainment Zone describes the mixing that is almost totally induced by the effluent discharge and the far-field mixing zone describes the mixing attributable to an ambient diffusion lake-induced dispersion.

Mixing Zone Field Study Conclusions

The mixing zone delineation resulted in the discharge plume of Outfall 001 achieving an average dispersion of between 15:1 to 20:1 within 400 ft of the outfalls for all three days of the field study. This distance was the maximum distance where jet entrainment was occurring and past this point, plume velocities and lake velocities were essentially the same. Rapid mixing of the effluent with receiving water occurred within 100 feet of discharge. The total mixing zone was defined as an area extending to a distance of 1,000 ft from Outfall 001 where a dispersion of 50:1 to 100:1 was achieved. This 1,000 ft distance from the Outfall was based on the regulatory definition of a mixing zone for temperature (327 IAC 2-1-6(k)(4)). During the field study, ambient levels (i.e., background receiving water) of conductivity (a non-degradable substance) were achieved throughout the water column at distances of 400 feet to 500 feet from the Outfall depending on wind conditions. Other conclusions from the field study were that wind direction influenced dispersion, with lower dispersion values measured during northerly winds. The model generally provided a more conservative estimate of dispersion than the actual monitored results. In other words, actual measured dispersion was greater than dispersion projected by the PDS model.

In summary, a mixing zone has been defined from the field and computer modeling results consisting of two areas. First, a discharge-induced mixing area with dispersion ratios of 15:1 to 20:1 extending radially about 400 ft from Outfall 001 was measured. At the edge of this area is where acute aquatic criteria would be attained. Second, an area of far-field mixing with dispersion ratios of 50:1 to 100:1 extending radially 1,000 feet from Outfall 001 was defined. All continuous chronic criteria and Lake Michigan water quality standards, as well as temperature, would be met at the edge of this 1,000 ft arc. Based on the field-measured dispersion achieved, the rapid and immediate turbulence and mixing, the observed lake and effluent velocities, and the area of the mixing zone, the use of a mixing zone can be environmentally protective of Lake Michigan. In addition, the PDS model can be used to generate conservative dispersion estimates for a variety of operational and environmental conditions.

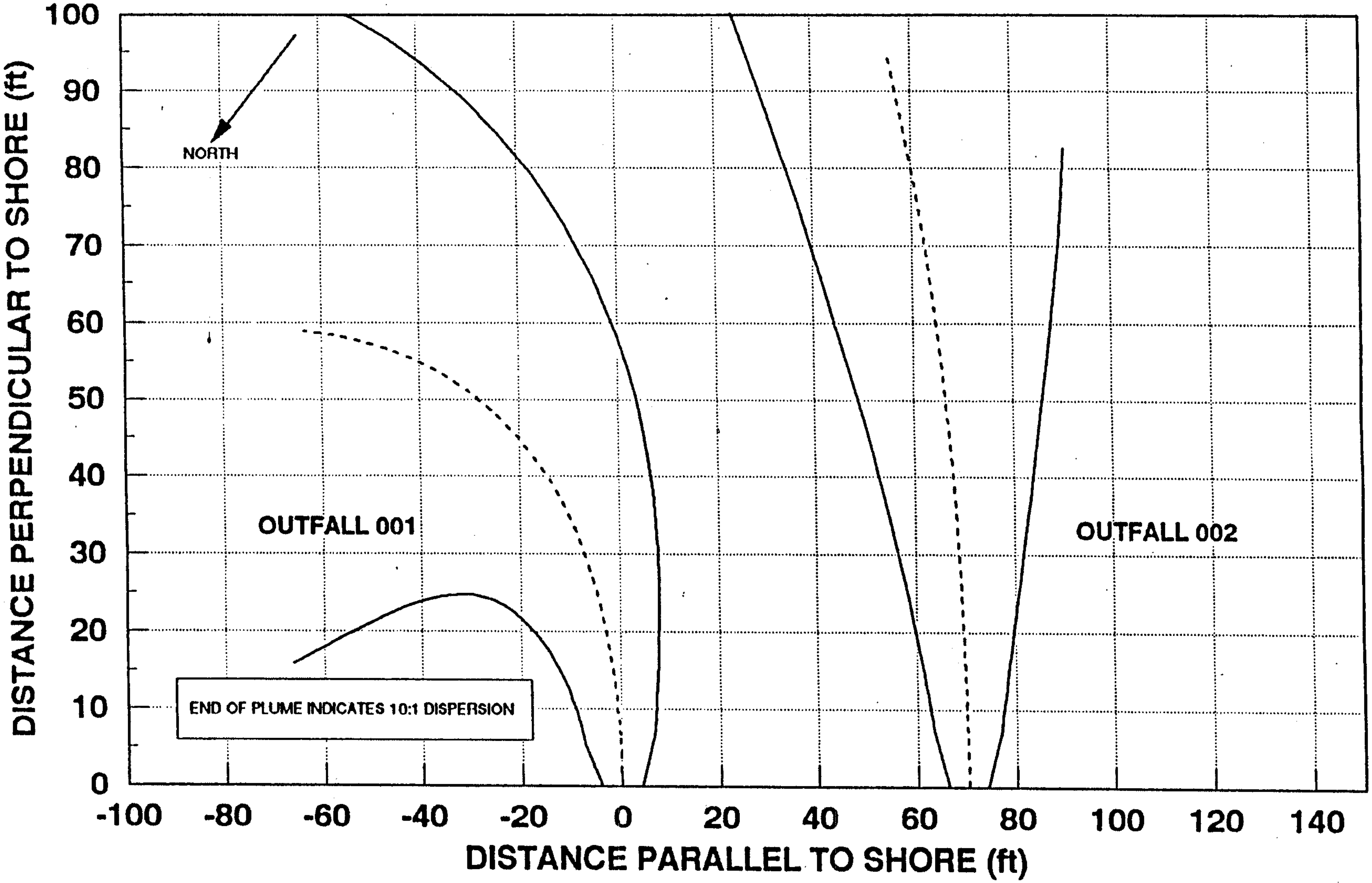

FIGURE 2-1

PLUME PROJECTIONS - PLAN VIEW

WIND DIRECTION = SOUTH

AUGUST 24, 1994

SECTION 3

MIXING ZONE DISPERSION ANALYSIS

The previous work demonstrated that the dispersion resulting from the existing outfall configuration is adequately protective of human health and the environment. Recognizing the critical importance of the south end of Lake Michigan water quality, Amoco decided, as part of its proactive water quality management program, to commit to the use of a multiport diffuser for the discharge of treated effluent from Outfall 001. Implementation of a multiport diffuser serves as an additional environmentally protective measure to enhance water quality within the receiving water. This would be accomplished by extending a diffuser out into deeper waters of Lake Michigan. Multiport diffusers can be thought of as "state-of-the-art" for discharge outfall structures as they are engineered to provide even more rapid, immediate mixing within a limited area. USEPA guidance (1991 TSD) specifies some of the design criteria using a multiport diffuser for mixing zone implementation.

MULTIPORT DIFFUSER MODELING

Amoco has evaluated a potential diffuser location (Site S3500) in Lake Michigan as shown in Figure 3-1. The rationale for this site is to maximize mixing with ambient waters by locating the diffuser in deeper waters where more water volume is available for mixing. Site S3500 is located in Lake Michigan approximately 3,500 ft from the current Outfall 001 in water depths of 28 to 30 ft. Specific benefits of a multiport diffuser at this location adding to the level of water quality protection include:

1) The diffuser, by design, provides even more rapid and immediate mixing in a small area.

2) The diffuser would be located offshore, thereby minimizing plume contact with Lake Michigan shoreline.

3) The diffuser site would be exposed to the general nearshore current/circulation patterns that enhance local mixing and flushing.

4) The discharge would be present in deeper waters completely submerged and surrounded by lake water available for entrainment (induced mixing). Vertical mixing would be achieved as the positively buoyant plume rises toward the surface.

In order to evaluate the magnitude (dispersion) and extent (size) of a mixing zone from a multiport diffuser, the USEPA-supported computer model CORMIX, developed by Dr. Gerhard Jirka of Cornell University, was used for analysis. Specifically, the CORMIX2 expert system was utilized to determine achievable dispersion at the edge of the Zone of Initial Dilution (ZID) as well as the total mixing zone (TMZ). CORMIX2 calculates plume characteristics (i.e., dispersion, plume width) for specific regions (modules) of the mixing zone which are defined by discharge and ambient water classification criteria. The specific regions are linked together by transition equations resulting in a complete projection of the plume up to a user-specified distance. Although several computer models are listed in the USEPA 1991 TSD, CORMIX2 has been recognized as the most useful model to regulators because of its expert system format CORMIX2 was also selected since it integrates both near-field and far-field projections with customized transition equations. The CORMIX2 model also features additional sensitivity to receiving water boundaries. CORMIX2 provided the model estimates given in the remainder of this report. As noted in Sections 1 and 2, computer models usually generate conservative estimates of achievable dispersion.

Model Input Parameters and Diffuser Design

The main criteria for development of an effective diffuser design is to maintain a specific port exit velocity at the average effluent flowrate. The USEPA 1991 TSD recommends maintaining a 10 ft/sec port exit velocity to ensure rapid mixing. If the effluent flow rate and exit velocity are known, the number of ports and port diameter can be determined for the diffuser. Table 3-1 presents various configurations for a diffuser discharging the average Outfall 001 flowrate of 13 mgd. For this analysis, a 90-ft diffuser with ten 6-in ports spaced 10 ft apart was chosen as an appropriate design for the Amoco discharge (see Attachment 3). The diffuser is unidirectional with all 10 ports pointing toward the center of the lake away from shore. The 6-in ports and 10-ft port spacing provide standard dimensions for ease of installation and still maintain a 10 ft/sec exit velocity (actually calculated as 10.3 ft/sec). Other configurations could be used for final design; however, port diameters should not be too small where clogging from debris might occur and spacing should be large enough where immediate entrainment of an adjacent port is avoided. Model sensitivity analyses from previous diffuser studies revealed slight differences in ZID dispersion for alternate design configurations, yet within the relative accuracy of the model.

Table 3-2 presents the remaining input parameters for the CORMIX2 simulations. From bathymetry measurements taken May 11, 1994, Site S3500 is located at a lake depth of 28.5 ft. Long term average effluent and lake temperatures revealed an annual average temperature difference of 17 °C. The effluent plume is usually warmer than the receiving water and a larger, more conservative temperature difference of 20 °C was used in the model. Field measurements of lake temperature, as shown in Table 3-3 revealed no significant temperature gradients in the Lake Michigan receiving waters representing a potential diffuser location. Actual field measurements of conductivity confirmed that both the effluent and lake are fresh water, therefore plume buoyancy is driven solely by temperature. The positively buoyant condition (effluent temperature greater than receiving water temperature) resulted in the use of a 0 degree (horizontal) port discharge angle, where the plume rises to the surface and is exposed to the full vertical water column.

Lake velocity (current) in nearshore Lake Michigan is influenced by several forces, primarily wind, and changes frequently in both speed and direction. Ambient velocity is a significant mixing force, especially in the far-field, as increased lake velocity will increase plume dispersion. Localized wind currents and along-shore physical features will create a continuously dynamic condition in the lake. For the location of S3500, wind currents provide the predominant transport mechanism. Based on Midway Airport meteorological data for 1974 to 1985 (Attachment 1), the prevailing wind direction for the south end of Lake Michigan is out of the south at an average speed of around 10 knots. A general engineering rule for conservatively estimating lake currents generated by surface wind is to multiply the wind speed by one-thirtieth (1/30) to obtain the wind induced lake velocity. Therefore, this would result in an average lake velocity of around 0.18 m/sec (0.59 ft/sec). This average velocity is consistent with past direct measurements in Lake Michigan. A summary of measured nearshore Lake Michigan currents, primarily for Argonne National Laboratory studies conducted in the Calumet area, is presented in Table 3-4. For purposes of this analysis, a conservative condition representing minimal velocity lake conditions was used. Based on historical review of measured lake currents in southern Lake Michigan, a conservative lake velocity of 0.10 m/sec was input to the model. The 0.10 m/sec lake velocity is less than velocity values derived from prevailing wind data and is consistent with actual measured values.

Model Results

For the input parameters described above, model runs were conducted for dispersion estimation as a function of distance from the diffuser at S3500. The model output is given in Attachment 2 and graphically presented in Figure 3-2. At S3500, the plume is fully vertically mixed in the ZID (per CORMIX2 classification) and extends to a distance of one-half diffuser length (45 to 50 ft). The one-half to one diffuser length distance provides a conservative guide for establishing the extent of the ZID (1980 Lee and Jirka). The dispersion achieved at this point is 54:1 for S3500. As discussed in Section 1, the 1991 TSD states that if the travel time through the acute mixing zone is less than 15 minutes, then the AAC (based on one-hour exposure) is not exceeded. CORMIX2 projects a time of plume travel of less than 90 seconds to reach the edge of the ZID (45 to 50 ft).

The 1991 TSD suggests that the ZID occupy 10 percent of the TMZ, therefore, an appropriate TMZ distance of 500 ft can be established for the Amoco diffuser. At this point, CORMIX2 projects effluent dispersion of 77:1.

SUMMARY

The mixing zone dispersion analysis for a multiport diffuser located at S3500, conducted per USEPA guidance, shows that this discharge configuration adds a degree of safety to protecting the quality of the receiving waters. This enhanced environmental protection is due to the rapid and immediate mixing that occurs within a small area. This is achieved by a "state-of-the-art" diffuser design and outfall location in the deeper Lake Michigan waters.

TABLE 3-1. PORT SIZES AND SPACING FOR A 90-FT MULTIPORT DIFFUSER

NUMBER OF PORTS	EFFLUENT FLOW (mgd)	EFFLUENT FLOW (cfs)	EXIT VELOCITY (ft/sec)	PORT AREA (sq ft)	PORT DIAMETER (in)	DIFFUSER PORT SPACING (ft)
1	13.0	20.1	10	2.01	19.2	
2	13.0	20.1	10	1.01	13.6	90.0
3	13.0	20.1	10	0.67	11.1	45.0
4	13.0	20.1	10	0.50	9.6	30.0
5	13.0	20.1	10	0.40	8.6	22.5
6	13.0	20.1	10	0.34	7.8	18.0
7	13.0	20.1	10	0.29	7.3	15.0
8	13.0	20.1	10	0.25	6.8	12.9
9	13.0	20.1	10	0.22	6.4	11.3
10	13.0	20.1	10	0.20	6.1	10.0
11	13.0	20.1	10	0.18	5.8	9.0
12	13.0	20.1	10	0.17	5.5	8.2
13	13.0	20.1	10	0.15	5.3	7.5
14	13.0	20.1	10	0.14	5.1	6.9
15	13.0	20.1	10	0.13	5.0	6.4

NOTE: 10-port diffuser selection based on design experience

TABLE 3-2. CORMIX2 MODEL INPUT PARAMETERS

PARAMETER	VALUE	RATIONALE
Effluent flow	13 mgd	Long term average
Port exit velocity	10.3 ft/sec	EPA TSD recommendation
Number of ports	10	Standard design (Table 3-1)
Port diameter	6 in	Standard design (Table 3-1)
Diffuser length	90 ft	Standard design (Table 3-1)
Port spacing	10 ft	Standard design (Table 3-1)
Port discharge angle	0 degrees	Optimizes plume buoyancy
Diffuser height off bottom	1.6 ft (0.5 m)	Practical estimate
Effluent temperature	30 °C	Long term average = 28 °C
Lake temperature	10 °C	Long term average = 11 °C
Temperture difference	20 °C	Conservative input
Minimal lake velocity	0.33 ft/sec (0.10 m/sec)	Conservative input

TABLE 3-3. LAKE MICHIGAN WATER QUALITY DATA

STATION	DATE	TIME	DEPTH (m)	TEMP (°C)	CONDUCTIVITY AT T oC (µmhos/cm)
S3500	05/10/94	1030	1	11.87	285
			2	11.87	285
			3	11.85	285
			4	11.86	285
			5	11.84	285
			6	11.86	285
			7	11.84	285
			8.1	11.85	284

TABLE 3-4. SUMMARY OF LAKE MICHIGAN CURRENT MEASUREMENTS

REFERENCE	DATE	FREQUENCY	NUMBER OF CURRENT METERS	CURRENT METER LOCATION	DEPTH	RESULT
Snow 1974	Nov. 8 to Dec. 8, 1973	20 min	3	At 68th St. Crib (1), Off Inland landfill (2)	5.2m (1) 3m and 6m (2)	Typical lake currents on the order of 0.05 to 0.15 m/sec
Saunders 1976	June 23 to Dec. 22, 1975	Continuous	5	3 km offshore from South Water Filtration Plant (SWFP)	12 m (mid-depth)	Strong currents observed for Nov. 17 to Dec. 22 Speed range = 0.15 to 0.30 m/sec Maximum speed = 1.0 m/sec
McCown 1976	Feb. 11 to Feb. 17, 1976	40 min	3	3 km offshore from SWFP	1m off bottom	Maximum speed observed was 0.15 m/sec
Harrison 1977 McCown 1978	Jan. 4 to Mar. 26, 1977	8 min	4	3 km offshore between Indiana Harbor Ship Canal (IHSC) and SWFP	1.5 m off bottom	Average speed = 0.015m/sec Root-mean-square speed = 0.074 m/sec Maximum speed = 0.15 m/sec Significant ice cover present late Jan-early Feb.

REFERENCES

Snow, October 1974, "Water Pollution Investigation: Calumet Area of Lake Michigan. Volume 1", IIT Research Institute.

Saunders, et al., May 1976, "Nearshore Currents and Water Temperatures in Southwestern Lake Michigan (June – December, 1975)", Argonne National Laboratory (ANL).

McCown, et al., July 1976, "Transport and Dispersion of Oil Refinery Wastes in the Coastal Waters of Southwestern Lake Michigan (Experimental Design – Sinking Plume Condition)", ANL.

Harrison, et al, December 1977 "Pollution of Coastal Waters off Chicago by Sinking Plumes from the Indiana Harbor Canal", ANL.

McCown, et al., November 1978, "Transport of Oily Pollutants in the Coastal Waters of Lake Michigan", ANL.

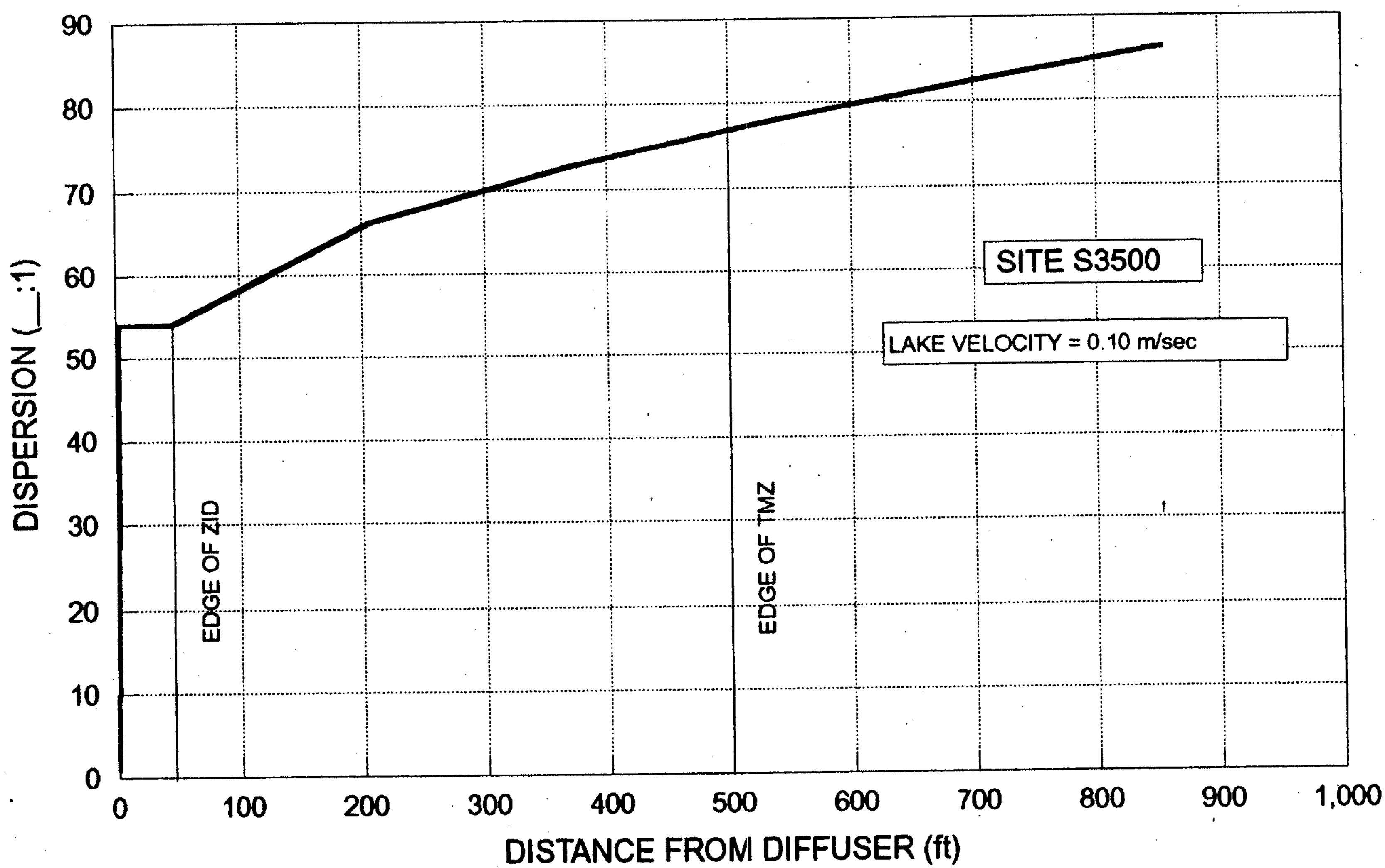

FIGURE 3-2
CORMIX2 RESULTS FOR MULTIPORT DIFFUSER

AUGUST 24, 1994

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SECTION 4

MIXING ZONE DEMONSTRATION

INTRODUCTION

To evaluate a proposed mixing zone, specific information must be provided to assure that granting a mixing zone for a discharge does not cause harm to the receiving water body. The necessary information for a mixing zone demonstration has been described by USEPA guidance and Indiana state rules to determine the boundaries of the mixing zone, the magnitude of mixing, an assessment of the impact of the mixing zone on the receiving water, and the steps taken to prevent acute lethality to aquatic life and prevent impairment of the use of the water. This information is evaluated to assure that it is environmentally protective to use a mixing zone for the discharge and to define the point of application of receiving water quality standards.

Amoco proposes that a mixing zone be included in its renewed NPDES permit. The following discussion describes the physical, chemical, and biological characteristics of the receiving water (southern Lake Michigan). It also describes the Amoco Outfall 001 discharge both at its present location and the proposed diffuser site. These characteristics are analyzed in context of the eight specific points noted in Indiana 327 IAC 2-1-4(b) to demonstrate that an appropriate mixing zone can be delineated in southern Lake Michigan consistent with Indiana and USEPA guidelines (1993 WQSH - Chpt 5, 1991 TSD - Chpt 2 & 4).

INDIANA MIXING ZONE REGULATORY REQUIREMENTS (327 IAC 2-1-4(b))

As discussed in Section 1, the USEPA provides guidance on determining and assessing the applicability of mixing zone implementation for a discharge. As previously shown in Table

1-4, these USEPA specifications are incorporated into the Indiana Water Quality Standards. The following text presents the Indiana Mixing Zone Guidelines regulatory language and Amoco's responses to the Guidelines. The eight guidelines addressed herein will provide information necessary to demonstrate that implementation of a mixing zone will not cause harm to human health and aquatic life. These eight guidelines are:

1. The dilution ratio
2. The physical, chemical, and biological characteristics of the receiving body of water
3. The physical, chemical, and biological characteristics of the waste effluent
4. The present and anticipated uses of the receiving body of water
5. The measured or anticipated effect of the discharge on the quality of the receiving body of water
6. The existence of and impact upon any spawning or nursery areas of any indigenous aquatic species
7. Any obstruction of migratory routes of any indigenous aquatic species
8. The synergistic effects of overlapping mixing zones or the aggregate effects of adjacent mixing zones

327 IAC 2-1-4(b)(1) - The dilution ratio

The dilution (dispersion) ratio has been optimized by the use of a high-rate submerged multiport diffuser located 3,500 ft from the current Outfall 001. Dispersion estimates were derived from the USEPA-supported model CORMIX2 as discussed in detail in Section 3. Conservative input parameters, including plume buoyancy and lake velocity, were utilized for the modeling. CORMIX2 results indicated a dispersion of 54:1 at a distance of one-half diffuser length (45 to 50 ft) from the diffuser. In the context of the Indiana regulatory language, the term ZID refers to an "area of the receiving stream after the end of the pipe where an instantaneous volume of water gives a one-to-one dilution of the discharge" (327 IAC 2-1-9). Under Indiana law, if a multiport diffuser is installed, this definition of a ZID does not apply, as a diffuser achieves better than one-to-one dilution. Therefore, a more appropriate description of the jet entrainment zone utilizing Indiana regulatory language for discharge induced mixing (327 IAC 2-1-9), is to define a Zone of Discharge Induced Mixing (ZDIM). The ZDIM is the area where turbulent initial mixing is provided by a high rate multiport diffuser which minimizes organism exposure time. The ZDIM is essentially equivalent to the ZID as defined by USEPA federal guidance.

Far-field projections indicated an appropriate TMZ dispersion of 77:1 achieved at a distance of 500 ft from the diffuser. The requested mixing zone for the Amoco multiport diffuser discharge is:

ZDIM: 54:1 dispersion at 50 ft from the diffuser

TMZ: 77:1 dispersion at 500 ft from the diffuser

A preliminary diffuser design is presented in Attachment 3.

327 IAC 2-1-4(b)(2) - The physical, chemical, and biological characteristics of the receiving body of water

Information about the southern part of Lake Michigan has been published in numerous studies. Attachment 4 is a bibliography of technical documents relevant to this part of the Lake. From a limnological basis, the deeper waters of Lake Michigan (open waters) begin about 5 miles offshore in the southern part of the Lake. The open waters of the lake respond to several physical forces (i.e. wind, thermal convection) which, in turn, affect the chemical and biological characteristics. Nearshore waters are most affected by local winds and shoreline and topographical features. These differences mean that the nearshore waters often have different physical, chemical, and biological characteristics than the open waters. Many Lake Michigan studies have been conducted on the open waters; these provide general information but may not apply to a nearshore area. Studies of the nearshore sites along the Indiana shore provide more information that may readily be extrapolated to the Amoco site.

Amoco conducted multiple field studies in Lake Michigan to characterize the physical, chemical, and biological characteristics of the receiving water and the mixture of the receiving water and treated effluent. These assessments included the proposed diffuser location as well as current Outfall 001 receiving waters inside the effluent dispersion area and outside the effluent dispersion area. These studies are further discussed in response to 327 IAC 2-1-4(b)(5), and a Field Bioassessment Data Summary report is presented as Attachment 5.

Southern Lake Michigan is a dynamic water body, particularly in the nearshore area that receives Amoco effluent and is dominated by localized winds. The background chemistry has been found to have suitable assimilative capacity for many constituents. The biological community in the vicinity is naturally limited due to the unstable sandy substrate and high turbulence. Mobile species are typically found throughout the area, including fish that may be attracted to the warmth of the cove area. However, little permanent, solid habitat to support complex biological communities occurs naturally in the area. Details regarding Lake Michigan physical, chemical, and biological characteristics are presented below.

Physical Characteristics - Open Waters. Several studies have been conducted to characterize the circulation and transport of Lake Michigan waters. The causes and characteristics of Lake Michigan currents are dependent upon the location within the lake. Snow (1974) describes the primary causes of lake transport in the open waters (away from shore) as wind forces, thermal convection, and Coriolis forces (rotation of the Earth). Other general lakewide influences include density gradients, atmospheric pressure, and precipitation.

The open waters of Lake Michigan respond to general seasonal transport patterns. Thermal convection (stratification) is a significant seasonal influence on general lakewide mixing and refers to the tendency of lakes to form distinct temperature layers. Stratification is typically observed in summer and winter. During summer, the surface waters, warmed by the sun, become less dense than the cooler, deeper waters. A boundary, known as the thermocline, separates the bottom waters from the surface waters. Photosynthesis in the upper, sunlit layer (the epilimnion) may alter the water chemistry, increasing dissolved oxygen levels, and decreasing the level of carbon dioxide and algal nutrients. Biological respiration and excretion below the thermocline (in the hypolimnion) tends to decrease dissolved oxygen levels and increase levels of carbon dioxide and nutrients. This stratification ends in autumn when the surface layer cools and the entire water column can more easily be mixed. During winter, another stratification may be established with the cooler waters on top of the Lake and the warmer water below. This type of stratification ends in spring. An important feature of this stratification is the seasonal availability of nutrients, particularly in spring, which can encourage blooms of algae and their consumers, the zooplankton.

Lateral mixing of open waters results in observable lake currents. Baumgartner (1968), in conjunction with the Great Lakes Region of the Federal Water Pollution Control Administration (FWPCA), presented the results of field studies to define the general open water currents in Lake Michigan. The investigators found that currents do exist in the Lake with complex interrelated flow patterns. Dr. Baumgartner testified: "[currents] vary in direction and magnitude from surface to depth, from length to width, and from side to side. The variability in time is significant on a seasonal basis, but important variabilities are also observed in shorter periods of time, such as days or even hours. Superimposed on the hourly variation is a continuous process of turbulent mixing of small parcels of water." Mortimer (1975) notes that the FWPCA report "does indeed present diagrams of average circulation for various seasons, depths, and wind regimes, but they are of little use for day-to-day prediction, because of overriding effects of short term fluctuations (internal waves and responses to local winds) and of the spatial complexity of these motions, particularly near shore."

Physical Characteristics - Nearshore Waters. Nearshore lake currents, such as those to be encountered at the proposed Amoco diffuser site, are caused primarily by localized winds with less influence from thermal convection or Coriolis forces. Vertical stratification is seldom observable in the shallower depths and, if present at all, not maintained for long periods. As evident from direct measurements at S3500 (Table 3-3), the temperature profile is uniform over the 30 ft depth with no direct gradient influences expected. Coriolis forces require travel distances much larger than the delineated mixing zone to be of any consequence to overall transport.

Lake currents in the nearshore area are also dominated by boundary effects due to shore and topographical features. The current motion in this well-mixed dynamic region is much more complicated and difficult to predict. Nearshore currents will mainly follow the general direction of the wind and, in the instance of the wind blowing towards the shore, the lake water will deflect to follow the shoreline. Wind forces of sufficient duration induce ambient velocities throughout the water column in shallow lake areas, such as the beach zone near Amoco's existing Outfall 001 discharge. Wind forces enhance the advective forces of the receiving water thereby increasing the mixing.

Several attempts of direct lake current measurements near the southwest Lake Michigan shoreline were made during tracer studies performed by Argonne National Lab in the 1970's. Saunders, et al. (ANL, "Nearshore Currents and Water Temperatures in Southwestern Lake Michigan (June - December, 1975)"), conducted continuous current measurements at five mooring stations located at mid depth approximately 3 km offshore of South Chicago. Currents in the region were predominately parallel to shore. As an example of typical results, the net motion of the water during November 17 to December 22, 1975 was toward the southeast, but at least 11 major current reversals occurred during this period. The strong currents ranged from 0.15 to 0.18 m/sec with maximum observations of approximately 1.0 m/sec. Other current measurement studies have been previously presented in Table 3-4.

The general lakeshore of the Indiana portion of Lake Michigan is characterized by beach dune areas with gently sloping shores. The bottom slope in the Amoco "cove" area has been previously calculated as about 0.7% (a 24 ft drop in about 3,400 ft). Snow (1974) described the major substrate component of the nearshore Calumet area as comprised of sand. Bottom sediments can be resuspended from wave action and storms, as indicated by increased turbidity of nearshore waters during these events. Ayers (1967) also described the sediments of the southwestern corner of the lake to range from silty sand to till, with fine to coarse sands covering most of the area. The substrate of Lake Michigan in the vicinity of Amoco's current discharge and proposed diffuser location is very similar to Snow's description. Based on the recent April - June, 1994 field studies, the bottom substrate is comprised primarily of homogeneous sand with some small fractions of silt. Particle size distributions, presented in Attachment 5, reveal the majority of sampling sites to consist of over 90% sand.

In summary, the diffuser will be located approximately 3,500 feet from the current Outfall 001 (see Figure 3-1) and does not encroach upon any navigation channels, docks, harbors, or water intakes. Bathymetric measurements at this site indicated water depths of 28.5 feet. The lake system is dynamic due to local wind driven currents, and complete vertical mixing occurs. The bottom substrate consists of fine sand.

<u>Chemical Characteristics</u>. The chemical water quality of the site is typical of the nearshore conditions of Lake Michigan. During the May 1994 field studies, no significant conductivity gradients were observed at the proposed diffuser site. General water quality parameter concentrations from the Amoco bioassessment studies are included in

Attachment 5. In addition, the USEPA STORET database includes monitoring data (1982-current) for many parameters for the Whiting Water Intake Crib. A STORET inventory retrieval with summary statistics is given in Attachment 6.

In developing the wasteload allocation for the Grand Calumet River-Indiana Harbor Ship Canal and Amoco, IDEM defined the background concentrations for certain parameters as presented in Table 1-4. These background concentrations are based on Lake Michigan monitoring data and indicate that the Lake has assimilative capacity for many constituents without exceeding the Indiana Water Quality Standards.

Biological Characteristics. In general, the extreme southern end of Lake Michigan has been classified as mesotrophic (Great Lakes Water Quality Board, 1977). This trophic status is intermediate between oligotrophic (clear water, low nutrient concentration, low biological productivity) and eutrophic (nutrient rich, highly productive). The mesotrophic classification was based on four criteria; phytoplankton, zooplankton, chlorophyll-a, and total phosphorus.

The biological characteristics of receiving waters in the vicinity of Amoco's existing discharge and proposed diffuser location are controlled by the natural physical setting. The gently sloping sandy bottom and naturally constant turbulence combine to exhibit characteristics of a flooded beach. This results in a very physically unstable habitat, which, combined with fluctuations due to seasonal factors, limits the potential for developing any complex ecosystem. Due to the dynamic nature of this "beach water zone" of the nearshore area, limited ecological studies have been conducted previously for this specific zone defined as less than 30 ft depth and less than two miles offshore (USFWS, 1970). As summarized later in this Section and in Attachment 5, extensive development and complex structure of the biological communities in the beach water zone was not common. Benthic organisms in particular showed low density and species richness. A summary of representative fisheries obtained from anecdotal information from local fisherman and boaters is presented in Attachment 7.

The Amoco cove plankton includes typical open water phytoplankton and zooplankton of southern Lake Michigan, though their presence is determined as much by the wind induced Lake currents than as by any other environmental factors. The shifting sand substratum of the beach water zone effectively limits complex benthic community development and productivity. The depth at the proposed diffuser site will likely reduce, but not eliminate, the restrictive effects of shifting sand substrates. The April to June 1994 studies conducted by Amoco of the bottom (benthic) habitat near the proposed diffuser location indicated a biologically insignificant benthic community comprised of a few midge larvae (Chironomidae) and worms (Oligochaeta). The introduction of the diffuser (a solid substrate) can be expected to result in some benthic colonization by the exotic Zebra mussel (*Dreissena polymorpha*) which occurs throughout the area, and has been found on the Amoco water intake crib.

327 IAC 2-1-4(b)(3) - The physical, chemical, and biological characteristics of the waste effluent

The Amoco Outfall 001 effluent is freshwater with a temperature greater than the receiving water, thereby resulting in a positively buoyant discharge plume. The long-term average effluent flow rate is 13 mgd and the multiport diffuser is designed to maintain a port exit velocity of 10 ft/sec at this average flow rate. The diffuser will be designed to operate and provide suitable dispersion over an effluent flow range of 7 to 44 mgd. This is the range of short duration flows observed over the past three years. Chemical and biological characteristics of Outfall 001 are presented in Volume I of this NPDES Permit Application. There are two major observations regarding effluent quality: 1) all maximum bioavailable concentrations of constituents are below the Indiana acute aquatic criteria; and 2) based on three years of effluent toxicity biomonitoring using standard USEPA methods and procedures, no acute toxicity has been measured or observed for the 001 effluent.

327 IAC 2-1-4(b)(4) - The present and anticipated uses of the receiving body of water

The Indiana portion of Lake Michigan is classified as an "outstanding state resource" to be maintained in its "present high quality without degradation". Indiana Water Quality Standards are applied to protect and maintain the designated use of waters of the state, including Lake Michigan. Water quality standards given in Table 1 (2-1-6(a)) shall apply as defined by their in-stream derivation at appropriate points based on time, exposure, duration, and frequency. Attainment of the water quality standards at their appropriate points assures continued designated use of the waterbody.

Lake Michigan is also used as a source of water for drinking water treatment plants. The Lake Michigan standards given in 2-1-6 (b)(5)(c), (j), and (k) will apply outside the total mixing zone to assure their intent of maintaining Lake Michigan as a source of drinking water. The nearest point of water intake is the Whiting Intake located approximately 2,500 ft from the proposed diffuser. The total mixing zone extends only to a distance of 500 ft from the diffuser. For those substances with primary drinking water standards, which are human health safety-based, as established by the Federal Safe Drinking Water Act, Outfall 001 maximum effluent concentrations are already less than these drinking water standards at end-of-pipe (prior to mixing with Lake Michigan) as presented in Table 4-1. In other words, Outfall 001 effluent contains smaller quantities of these substances than the concentrations given as the federal primary drinking water standards. Thus, Amoco's projected mixing zone will not adversely effect Lake Michigan as a source of drinking water.